# Solar potential in extreme climate conditions: comparative analysis of two district case studies in Norway and Reunion Island

Aymeric Delmas, Gabriele Lobaccaro, Michael Donn, Marjorie Musy, François Garde

# Solar potential in extreme climate conditions: comparative analysis of two district case studies in Norway and Reunion Island.

**Aymeric Delmas[1, 4], Gabriele Lobaccaro[2], Michael Donn[3], Marjorie Musy[4], and François Garde[1]**

[1]PIMENT
Le Tampon, Reunion Island
aymeric.delmas@imageen.re
francois.garde@univ-reunion.fr

[2] Norwegian University of Science and Technology
Trondheim, Norway
gabriele.lobaccaro@ntnu.no

[3] Victoria University of Wellington
Wellington, New Zealand
michael.donn@vuw.ac.nz

[4] CRENAU
Nantes, France
marjorie.musy@ec-nantes.fr

**ABSTRACT**

This work aims to investigate the application and replicability of parametric solar design to both existing and future development urban areas in two extreme climate conditions: *Øvre Rotvoll* in Norway (subarctic climate) and *Ravine Blanche* in Reunion Island (tropical humid climate). The interplay between urban morphology and its potential for passive and active solar energy strategies has been investigated. The methodology combines the parametric modelling software *Rhinoceros-Grasshopper*, with two *Radiance*-based solar simulation tools to optimise the solar potential of a district. The application of a new workflow is studied over the computation of various design scenarios in an existing urban environment at both the district and the building scale. The results show differences and similarities between climate-specific interventions that can be used as supportive instruments for the on-going local planning processes. The study demonstrates how parametric optimisation allows maximising the solar potential of urban areas at different latitudes despite climatic and urban densification constraints.

**Author Keywords**

Urban Simulation; Design & Optimisation; Parametric Design; Solar Urban Planning, Extreme Climate Conditions.

## 1 INTRODUCTION

In the current scenario of urbanisation and global warming, an informed use of solar energy in urban planning aims to increase the quality and efficiency of the built environment. In that regards, developing solar active and passive solutions architecturally integrated in urban morphology [1] is one of the key strategies. The numerous urban parameters, the design constraints (i.e. maximum building height, plot ratio, distance from the borders) and the complexity of the dynamic 3-dimensional interplay between solar irradiation and the urban morphology, represent a real challenge for designers and urban planners who need flexible and performative tools for studying these phenomena [2]. In this context, a new approach combining parametric design tools with dynamic simulation software to optimise the solar potential of urban typologies, patterns and building shapes has recently become a pivotal issue [3, 4, 5, 6].

This paper introduces a workflow to fully exploit the solar energy potential of urban settlements. The proposed approach is to maximise the annual global solar irradiation received by the roofs and façades of both new and existing buildings. The developed methodology integrates a scale-flexible optimisation process that limits adverse solar availability reduction over the existing environment. Finaly, this work aims to demonstrate the applicability and replicability of the workflow and the methodology, by positive optimisation results of various design scenarios in two extreme climate conditions (tropical and subarctic).

## 2 METHODOLOGY

The application of the aforementioned approach was tested in two different district case studies situated in extreme climate conditions: (i) a future urban development area, *Øvre Rotvoll*, located in Trondheim, Norway (latitude 63°36'N); and (ii) a newly renovated neighbourhood, recently awarded ‘eco-district’ status, *Ravine Blanche* in Saint-Pierre, Reunion Island (latitude 21°20′S). The two districts are under a significant densification development and comprise new building projects that were planned without taking into account the challenges deriving from solar energy integration and mutual interactions in urban environments. Urban densification aims to reduce urban sprawl by limiting the use of new soil and to improve the energy efficiency. However, most of the time those aspects affect the solar accessibility and the integration of solar technologies in the urban environment by creating overshadowing effects on new and existing buildings.

### 2.1 Tools

This work uses a solar urban design platform, developed on the software pair *Rhinoceros-Grasshopper*. *Rhinoceros* [7] and the visual programming tool *Grasshopper* [8] allow parametrical control and generation of complex 3D models. *Ladybug* [9] and *DIVA for Grasshopper* [10] as *Radiance*-based tools developed for the *Rhinoceros-Grasshopper* platform were selected for their user-friendly interfaces and high accuracy for simulating solar irradiation in complex urban environments [2]. Finally, the evolutionary algorithm *Galapagos* [11] was used to solve the multi-objectives problem of simultaneous maximisation of new and existing buildings' solar potentials (both potentials are treated equally in the fitness function of the problem).

### 2.2 Parametric building model

A unique architectural brief was defined in two extreme latitudes in order to evaluate the influence of the climate over the process of solar potential in urban planning. The defined brief comprises two buildings: a residential block and a media library (respectively (a) and (b) in Figure 1). Both buildings are planned interventions in the district of *Ravine Blanche*, with assigned land parcels of respectively 1,550m² (a) and 3,700m² (b). These two buildings represent perfect case studies for parametric design optimisation. They were selected in order to test the influences of solar accessibility on the urban surrounding in the tropical climate of Reunion Island and in the subarctic climate of central Norway.

### 2.3 Simulation parameters

The *Radiance* and material parameters used in *DIVA for Grasshopper* for simulating the annual global solar radiation received on the buildings' envelopes in both Saint-Pierre and Trondheim were validated in a previous study [6] and are summarised in Table 1. Typical .epw weather data files were used in the simulations.

### 2.4 Design and optimisation process

A global, multi-scale and multi-objectives approach was developed in order to maximise the solar potential at both district and building scale and to minimise the impact on the solar accessibility on the existing urban surrounding. This approach comprises four design stages:

1. From the brief's footprints and the maximum building height authorised in the district (12m), the maximum buildable volumes of the two buildings are generated (around 63,000m³ in total). They are represented by the blocks (a) and (b) in Figure 1.
2. A solar map analysis is performed in order to identify the overshadowing issues generated by the integration of the new buildings (top picture in Figure 1) in the two climates. The most critical parts of the built volumes in terms of solar accessibility (dashed framed in Figure 1), are subdivided into several smaller volumes representative of the existing buildings of the district ((1) to (6) in Figure 1).
3. Coupling *Ladybug* and *Galapagos*, the location of the smaller volumes over the available land (area in dark hatch in Figure 1) is optimised in order to maximise the annual global solar radiation received by their buildings' envelopes and to reduce as much as possible the overshadowing effect on the nearby buildings (distance < 100m). The other surrounding areas (100m < distance < 200m) are also considered in the analysis.
4. At the final stage, coupling *DIVA for Grasshopper* and *Galapagos*, a second set of simulations allowed optimising the solar potential of the generated building shapes through more climate-specific transformations of the façades. The slope of its main façade (from -10° South to 10° North) but also the orientation of the façades (rotation of its roof; from -10° West to 10° East) were optimised in the two locations.

| | **Ambient bounces** | **Ambient division** | **Ambient super-sample** | **Ambient resolution** | **Ambient accuracy** | **Specular threshold** | **Direct sampling** | **Direct relays** |
|---|---|---|---|---|---|---|---|---|
| **Simulation parameters** | 1-3 | 1000 | 20 | 300 | 0.1 | 0.15 | 0.20 | 2 |
| | **Material** | **Radiance material** | **Number of values** | **R refl.** | **G refl.** | **B refl.** | **Specularity** | **Roughness** |
| **Material parameters** | Concrete block | Void plastic | 0 0 5 | 0.549 | 0.549 | 0.549 | 0.00 | 0.00 |

**Table 1.** Radiance simulation and material parameters used for analysis [6].

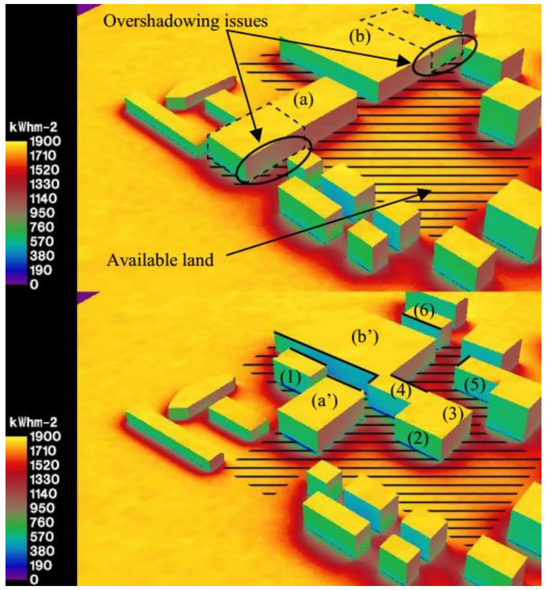


**Figure 1.** Annual solar map (South East view) of the *initial scenario* (top) and *solar optimised urban scenario* (bottom); climate of Saint-Pierre.

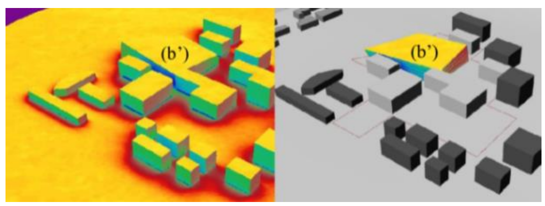


**Figure 2.** Annual solar map of the *solar optimised building scenario* for Saint-Pierre (left) and East rotated building scenario (right).

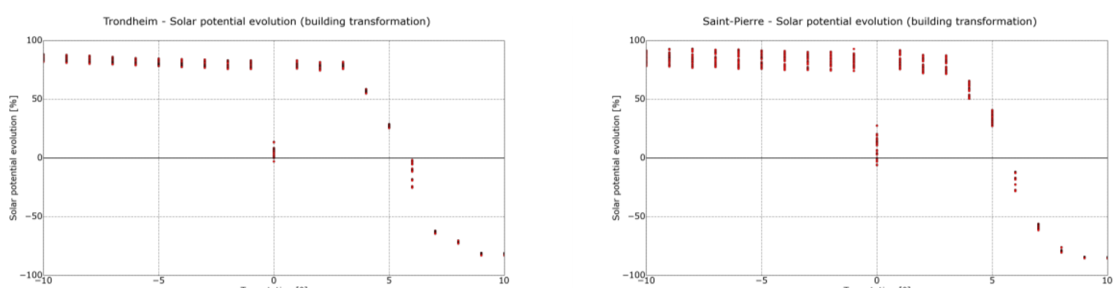


**Figure 3.** Solar potential evolution function of the building top rotation for two extreme climates.

## 3 RESULTS

### 3.1 Solar potential of the districts before the integration of the new buildings

The global solar radiation received by the nearby buildings (distance < 100m) on the design site was calculated and used as reference case (*initial scenario*). In the *initial scenario*, the district has a solar collection potential of 32,148MWh in Saint-Pierre and 15,848MWh in Trondheim. In the conducted analyses, at the district scale only the overshadowing effect between the buildings was taken into account; while at the building scale (section 3.3) the simulations were run by setting 3 ambient bounces in order to calculate the mutual reflections between buildings' façades and the ground.

### 3.2 Optimisation of the building blocks' location in two extreme climates

The maximum buildings' volumes (a) and (b) led to several critical solar accessibility issues on the existing buildings. Due to close relative positions on the East and West façades, a reduction in terms of solar potential was estimated in both climates (Figure 1). In order to avoid the reduction of solar accessibility of the district, the most affected parts of the new buildings' volumes (dashed framed volumes in Figure 1) were divided into several smaller volumes by keeping the original distribution's volume constant. Their positions were optimised within the borders of the available land site by maximising the solar radiation at the district scale. This optimisation process is inspired and adopted from *the Solar Dance* method, originally developed by Igor Mitrić Lavovski [12]. Additionally, in order to architecturally integrate the new building's volumes in the existing urban environment, their dimensions were set in order to be representative of the typical local buildings populating the area (small rectangular blocks with average dimensions of 12m height, 12m width and 24m long). This led to the generation of 6 new building shapes.

The total annual solar radiation received by building (a'), building (b'), the new six generated building volumes and their surroundings was calculated over 400 building positions, automatically generated and simulated in both locations by using *Galapagos*. A cross analysis of the results allowed the identification of the best layout (*solar optimised urban scenario*) that maximises the total solar potential of the district (aggregation of new and existing buildings' received irradiation) by 3.6% and 10.1%, in Saint-Pierre and in Trondheim respectively.

The integration of the new buildings generates a limited solar potential reduction over the existing buildings of about 1.7% in Saint-Pierre and 1.9% in Trondheim compared to the *initial scenario*.

### 3.3 Climate-specific optimisation of a building

The optimisation at the building scale was conducted by using the morphology of the *solar optimised urban scenario* as baseline. The buildings' shapes were optimised in order to exploit the maximum solar potential and to minimise the impact on the surroundings' buildings' façades. Surrounded by three buildings, building (b') was selected as case study. Its shape was twisted along the rotation of its roof (from -10° West to 10° East) and sloped along its main façade (from -10° South to 10° North), independently in both locations. The range of transformations was kept narrow in order to make the final building's shape structurally feasible, not interfering with the surrounding ones and harmoniously integrated within its urban environment.

The solar radiation was calculated over the façades of the *solar optimised building (b') scenario* (Figure 2, left) and its nearby buildings. In both climates, the optimisation of the global solar radiation received by the analysed façades (highlighted in Figure 1) gives relevant improvement up to 88% in Saint-Pierre (tropical climate) and up to 93% in Trondheim (subarctic climate) compared to the *solar optimised urban scenario*. Regarding the surrounding buildings, whereas in Saint-Pierre the optimisation gives more than 10% of reduction of the solar potential, in Trondheim the process allows reaching an increase up to 2%. The relative transformations for building (b') are: -10° West rotation for the roof, -10° South slope for the façade in Saint-Pierre (Figure 2); and -8° West rotation for the roof, 10° North slope for the façade in Trondheim.

## 4 DISCUSSIONS

### 4.1 Influence of the climate on the design process

At the district scale, the *optimised urban scenario* shows better improvement compared to the *initial scenario* for the latitude of Trondheim than in Saint-Pierre. This demonstrates that the building placement optimisation process favours the reduction of the overshadowing effect caused by the low sun angles of a city close to the poles than for a city closer to the equator. Future developments of the current study should correct this feature as well as integrate penalty clauses in the fitness function of the genetic algorithm in order to exclude unwanted generated scenarios such as buildings with too close relative positions or with common walls.

From the building scale optimisation, some outcomes are qualitatively confirmed. As expected, the design process of the façades must take into account the influence on the nearby buildings as well as the solar accessibility of the optimised building. In the southern hemisphere, the most optimised solar potential of the façades is obtained for a North sloped façade. On the contrary, in the northern hemisphere, the optimal transformation is for a South sloped façade. From the analysis of the evolution of the solar potential of the analysed façades function of the two separated building's transformations (Figure 3), similar patterns are observed in both climates. Moreover, whereas the results for the façade's slope transformation do not present any distinct relationship with the evolution of the solar potential, the roof's rotation of the building towards the East can have critical effects over the reduction of the solar potential of the buildings between 2.5° and 10° East (Figure 3). This is explained by the fact that in both locations, the East rotation closes even more the gaps between the buildings (b'), (1) and (6). This transformation accentuates the self-shading and overshadowing effects (Figure 2, right), whereas the West rotation increases the North and South gaps by maximising the area of the radiated façades.

## 5 CONCLUSION

This external solar and geometry-based study demonstrates the great potential that represents the coupled use of the parametric modelling tools *Rhinoceros-Grasshopper* with *Radiance*-based simulation tools for solar urban planning. Thanks to their flexibility and accuracy, it is possible to maximise the solar potential of a district at various scales; as well as to analyse the complex overshadowing effects and mutual reflections within the urban environment. The use of evolutionary algorithm tools, such as *Galapagos*, allows generating numerous design scenarios, identifying optimised ones, avoiding local optima and limiting solar availability reduction. This is a critical aspect in dense areas, where energy need is higher and where ensuring solar accessibility is more complex due to the number of buildings' interactions. The solar analyses show that maximised solar energy integration for both existing and new buildings is possible throughout simple form optimisations. This study demonstrates that such processes can be successfully applied in extreme latitudes (here in tropical and subarctic climates), where specific climate constraints are relevant. Finally, the advantage of using evolutionary algorithm has been highlighted by its remarkable flexibility to tackle a wide variety of problems. Its degree of interaction with the user, who can compare and explore sub-optimal solutions during the optimisation process, is a unique and valuable feature in multi-scale problems where environmental performance must meet urban design quality. In further developments, such methodology could be used in local planning processes, as urban decision support instruments, by designers and urban planners.
This work is part of a doctoral study dealing with the design of optimised bioclimatic buildings in dense tropical urban areas using generative modelling tools with various climate-based tools. In future works, the scale-flexible approach introduced in this paper will be further developed in order to investigate the use of the urban energy potential through the parametric design of roof and facade modules, for optimising external and internal performance objectives (PV and thermal generation, daylighting level, thermal comfort, etc.).


## ACKNOWLEDGMENTS

The authors thank all the students who attended the Winter Workshop on *Parametric modelling and Solar Energy in Urban Planning*, co-organized by the ESIROI Engineering School with the Norwegian University of Science and Technology. The educational activity was framed within the International Energy Agency – SHC program Task 51 *Solar Energy in Urban Planning* [13].


## REFERENCES


1. Scognamiglio, A. et al., 2014. How net zero energy buildings and cities might look like? *Energy Procedia*, 61, 1163–1166.
2. Freitas, S. et al., 2015. Modelling solar potential in the urban environment: State-of-the-art review. *Renewable and Sustainable Energy Reviews*, 41(C), 915–931.
3. Amado, M. et al., 2014. Solar Urban Planning: a parametric approach. *Energy Procedia*, 48, 1539–1548.
4. António, C.A.C. et al., 2014. Optimal topology of urban buildings for maximization of annual solar irradiation availability using a genetic algorithm. *Applied Thermal Engineering*, 73(1), 424–437.
5. Montavon, M., 2010. *Optimisation of urban form by the evaluation of the solar potential*. EPFL.
6. Lobaccaro, G. et al., 2012. District geometry simulation: a study for the optimization of solar façades in urban canopy layers. *Energy Procedia*, 30, 1163–1172.
7. Robert McNeel & Associates. *Rhino3d.* www.rhino3d.com.
8. Grasshopper. *Algorithmic Modelling for Rhino.* www.grasshopper3d.com.
9. Roudsari, M.S. et al., 2013. Ladybug: a parametric environmental plugin for grasshopper to help designers create an environmentally-conscious design. *Proc. of the 13th IBPSA Conference.*
10. Solemna. www.solemma.net.
11. Rutten, David. *Galapagos Evolutionary Solver.* www.grasshopper3d.com/group/galapagos.
12. Lavovski, Igor Mitrić. *the Solar Dance.* www.grasshopper3d.com/profiles/blogs/the-solar-dance.
13. International Energy Agency. *Solar Energy in Urban Planning. http://task51.iea-shc.org.*